DOCUMENT RESUME

ED 292 643 SE 048 992

TITLE	Educational Technology Center First Year Report.
INSTITUTION	Educational Technology Center, Cambridge, MA.
SPONS AGENCY	National Inst. of Education (ED), Washington, DC.
PUB DATE	Nov 84
CONTRACT	400-83-0041
NOTE	54p.; For the second and third year reports, see SE 048 993-994.
PUB TYPE	Reports - Descriptive (141) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	College Mathematics; College Science; Computer Assisted Instruction; *Computer Uses in Education; Courseware; *Educational Technology; Educational Television; Higher Education; Interactive Video; Mathematics Education; *National Programs; Programing; *Research Projects; Science Education; Secondary Education; *Secondary School Mathematics; *Secondary School Science
IDENTIFIERS	Mathematics Education Research; Science Education Research

ABSTRACT

The Educational Technology Center (ETC) was established by the National Institute of Education in October, 1983, in order to find ways of using the computer and other information technologies to teach science, mathematics, and computing more effectively. This report describes the ETC, presents its framework for research, and summarizes work on 14 research projects. These projects dealt with the following topics: (1) fractions; (2) word problems; (3) heat/temperature; (4) weight/density; (5) scientific theory and method; (6) complex systems; (7) machine handling; (8) programming; (9) applications; (10) speech recognition; (11) state-of-the-art software and educational television; (12) interactive video; (13) science networking; and (14) national and local networks. (TW)

EDUCATIONAL TECHNOLOGY CENTER

First Year Report

The Educational Technology Center is operated
by a consortium comprising

Harvard Graduate School of Education
Cambridge Public Schools
Children's Television Workshop
Educational Collaborative for Greater Boston
Education Development Center
Educational Testing Service
Interactive Training Systems
Newton Public Schools
Ware Public Schools
Watertown Public Schools
WGBH Educational Foundation

November, 1984

This is the annual report on the Educational Technology Center's work under contract NIE-400-83-0041 from the National Institute of Education. Opinions expressed herein are not necessarily shared by NIE and do not represent Institute policy.

TABLE OF CONTENTS

EDUCATIONAL TECHNOLOGY CENTER

First Year Report

Perhaps the most efficient way to begin a report on the first year of the Educational Technology Center is to focus on a few stories, which are at once unique and representative. These stories will help evoke the feel of the Center's first year and illuminate the more orthodox reports which follow. We will begin with a conversation about balloons which emerged from a research group studying computer simulation of complex systems and which evolved over several days this past spring, then turn to a meeting of the Agenda Group, then touch on the second of the year's off-site Institutes, and conclude with glimpses into the methodological state of projects involving the use of computers to reduce weight/density confusions and to overcome difficulty with word problems.

Just a word about the ETC structure before the stories begin. The Center's research is divided roughly into two areas. The projects in the first of these -- the larger by far -- focus on the use of computers to improve instruction in math, science, and computer subjects. The second comprises projects focusing on new technologies likely to be important educationally. In addition to research, the Center comments on the research agenda in educational technology, does limited graduate-level training, and disseminates results of its work.

The specific projects within the first general research area emerged from three large working groups of teachers, scholars, experts in educational technology, and educational researchers. The focus of each project was to be a particular piece of curricular subject matter which met four criteria: (1) that it be widely perceived as difficult to teach, even for good teachers; (2) that it be widely perceived as difficult to learn, even for good students; (3) that it be an essential part of the foundation for more advanced study; and (4) that there be a reasonable argument that technology might help teachers teach and students learn the piece of subject matter more effectively. The Center's label for such project foci, which has been a useful metaphor, is "Targets of Difficulty".

Balloons

One proposed target of difficulty which emerged from the science group involved complex systems. Many scientific phenomena important in school curricula involve the interaction of many variables to produce a result with many attributes. Yet much of the science curriculum focuses on relationships between pairs of variables. A major reason for this is the difficulty of teaching students how complex systems behave, which in turn reflects the difficulty of creating meaningful laboratory or field experiments that illustrate complex-system behavior. Nevertheless it is difficult for students to become skilled in any biological or applied physical science without a good understanding of complex systems.

Computer simulation, the science group believed, might make it possible to bridge this teaching gap.

What rapidly became clear was that most of the complex systems the group had in mind -- acid rain, ecosystems, deer populations, weather, traffic, and so on -- were too complex for research purposes. As discussion proceeded, and the composition of the group evolved, its focus sharpened in two ways: toward simpler though still complex systems, and toward a sense of what students ought to know about complex systems. The result was a proposal to teach two simple yet complex systems -- one involving the rise and fall of helium balloons, and the other involving the depth of a steadily replenished but leaky container of water -- using both a physical experiment and a simulation. The focus of the teaching experiment was to be the concept of equilibrium, and the effect of different variables on the system's steady state.

The next step was to refine the model systems, beginning with the balloons. The general idea was quite simple. A helium-filled balloon rises when its lift, which results from the low density of helium relative to air, exceeds its weight. Usually such a balloon has a string tied to it, and children rapidly learn that releasing the string, even momentarily, entails a rapidly rising -- and therefore lost -- balloon. The usual solution, tying the balloon to the child, works because the weight of the balloon-string-child system exceeds the typical balloon's lift. Another way to solve the lost-balloon problem is to use a very long string. In this case the balloon goes up until the weight of the string it is lifting is equal to the available lift. Actually, since the balloon usually rises rapidly it often lifts more string than it can sustain, falls back down until there is too little string to hold it, rises again, and so on until it settles in midair.

Although it appears simple, the balloon-string system is quite complex. Its equilibrium point depends on the balloon's lift, the balloon's weight, the string's length, and the string's weight per unit of length. Each of these, in turn, depends on other variables: for example, the balloon's lift depends on the amount of helium it contains, the elasticity of the balloon itself, the surrounding atmospheric pressure, and the ambient temperature. The amount of helium in the balloon depends on the amount blown into it originally and the amount lost through the balloon's wall, which in turn depends on the porosity of the plastic and the elapsed time since inflation. Yet, despite all this complexity, the behavior of the system is easy to observe, and at some level of abstraction easy to explain.

The Center bought a cylinder of helium, some balloons, and some string. We made balloon-string systems, and asked a variety of people to formulate hypotheses about the system's equilibrium. The debates were fascinating. What would happen to the equilibrium point if the string's mass per unit length doubled? (It would lower, by about half.) And if the string lay on a tile rather than a carpeted floor? (This created a sex bias among observers, since the closest tiled floor was in the men's room; the men's finding: slower to equilibrium, but point unchanged.) What about knots in the string?

This last produced a long debate among a physicist, several research assistants, the Center's administrative assistant, and the man from Nynex who was installing a new telephone system. The hypothesis they agreed to finally, was that provided the knot never touched the ground it would lower the balloon but leave the point at which string touched ground unchanged. Then they proceeded to an interesting discussion of how to measure the equilibrium point. The experiment which ensued at long last sadly contradicted their hypothesis, suggesting that the knot made the string heavier, since the touch point with knot was further up the string than the pre-knot point measured earlier. The problem, it turned out, was that the balloons in use were too porous for helium, and so their lift had diminished while the argument was underway. This had two consequences: it caused the Center to consult an expert, in the person of a gentleman who sells helium balloons each Saturday on Cambridge Common, on the matter of how to secure better balloons; and it made clear the need to include an unanticipated variable -- helium loss -- in the computer simulation when it was implemented. Had the long argument not taken place it is likely the simulation would not have included helium loss over time as a variable, and as a result the simulation would not have mimicked the behavior of the physical system over long times. On such details do computer simulations thrive or perish.

This story illustrates two recurrent themes in the Center's work. First, understanding the subject matter being taught is important to the design of educational technology, and this understanding rarely becomes clear until it has been approached from several diverse perspectives. Second, there must be ample opportunity for various perspectives on a piece of research to play against one another, lest focus and design be fixed prematurely and inappropriately.

Agenda Group

The Center is committed to building and guiding its research agenda through a process that includes a variety of perspectives -- those of school people, scholars, researchers, and technologists. This commitment is most apparent in the composition of research groups, which have been diverse from inception. The keys to eliciting interesting, important, collaborative research from these groups have been four: (1) a task to be done, which meant that specific research plans had to follow rather than precede the groups' work; (2) time to do the task well; (3) skilled support for groups as they traversed several symbolic, historical, organizational, and disciplinary minefields; and (4) a research-review process which did not contradict the research- formulation process.

The Center's Agenda Group has as its primary task continuing attention to research on educational technology, both within and without the Center. It comprises senior representatives from each of the organizations in the Center collaborative. The Agenda Group also serves as the Center's steering committee, advising the co-Directors on most major decisions about the Center and reviewing specific proposals for Center research and other projects. The Agenda Group appears unlike the research groups in that it comprises senior, primarily administrative

individuals. It is an excellent review group, however, since its members all have substantial -- though extremely varied -- educational and research experience.

A meeting late last spring was a case in point. The Agenda Group had in March approved the general statement and design for each project at the Center, and at the end of March had published summaries of these constituting the Research Agenda. In late spring it was time to review more specific research plans, and in some cases changes in original plans. For the most part the meeting moved quickly, but three items led to complicated discussion.

The first controversial item concerned the Fractions project, which focused on students' understanding of fractions as measures of continuous quantity rather than as objects to be manipulated according to counterintuitive rules. Judah Scwhartz, who spoke for the project, presented the group's premises and design in relatively telegraphic form, relying heavily on evocative but unconventional words such as "betweenness". Judi Sandler, representing the Education Collaborative for Greater Boston on the Agenda Group, pointed out that the project as presented bore little relation to what is commonly meant by "studying fractions" in schools, and that therefore its results were unlikely to engage teachers' attention. This, as it happened, was an issue which had emerged within the Fractions group as well. Further discussion made it clear that the group intended better connections with practice than its written summary suggested, and assurances from Schwartz allowed discussion to proceed.

At this point Dan O'Connor, superintendent of the Watertown schools, reiterated a point he had made at earlier meetings: teaching fractions, he said, was a solved problem, and an essentially unimportant one at that in the age of cheap calculators. Schwartz responded that while the calculator may solve the problem of computing with fractions, it did not solve the problem of understanding them. This provoked a spirited discussion of how one decides what is "important" and of when the existence of a conventional way to teach something means that the something is being taught well or deeply enough. Neither Schwartz nor O'Connor was much persuaded by the other's arguments, but the sense among the Agenda Group was clearly that the progress of the Fractions research would itself help clarify its value. The Fractions research was approved, but the Agenda Group expressed a clear desire to watch it carefully and reconsider its importance.

The second controversial item concerned one of the New Technologies projects. Kim Storey of WGBH had worked with Keith Mielke of CTW, Harry Lasker of ITS, and Ron Slaby of Harvard to refine a research project exploring the use of technologies combining traditional video materials (recorded or broadcast), videodisc players, and microcomputers running software which might come in conjunction with a broadcast and/or control the videodisk player. Here O'Connor was a proponent, commenting that this was the most interesting and clearly presented project he had seen. Other Agenda Group members were less enthralled, arguing that the technologies to be studied were too vaguely specified, that the material to be used was inappropriate, and that the relevance to school practice

of the technology and materials to be studied was unclear. During the discussion it became clear that this last problem was the critical one. Here, as in the case of Fractions, the Agenda Group decided to pursue an unresolved question by attending carefully to the progress of the project which raised it.

The third controversial item concerned the Applications project within the Center's computer-education area. Marlaine Lockheed of ETS, who spoke for the project, had provided an exceptionally detailed research plan which itself elicited little discussion. However, it rapidly became clear that in some ways the Applications research question (1) was very different in form from the rest of the Targets of Difficulty research projects and (2) crossed, rather than paralleled, the research questions in other projects.

The Applications project began with the observation that computer literacy could mean knowing how to make the computer do something, which entailed the typical programming-based computer course, or could mean knowing how the computer related as a tool to diverse fields of study, which entailed at least a course comprising different application tools and perhaps the replacement of computer courses with computer applications distributed among existing courses. The group was interested in how widespread the latter model was, in whether schools should proceed toward it, and in how they might do so. Its research question therefore included all of the other Targets of Difficulty groups' research questions, since these questions spoke to applications within subject-matter areas.

The Applications project crystallized an issue the Agenda Group had faced in more general form since the Center's beginning: when is it appropriate, given limited resources, to move beyond a research model carefully chosen to make effective use of these resources (in the Center's case, this model is the one focused on Targets of Difficulty)? The answer, of course, is that departure from a rule makes sense when it leads to more effective use of research resources than adherence to it would. The problem is to decide when this is so. The issue had surfaced in the Agenda Group's own discussions, in responses from peer reviewers to the Center's plans, and within research groups. Here, as before, although the question facing the Agenda Group was a familiar one -- that is, one that typically arises in complex research organizations -- the Center was too young for it to have developed a common-law answer. The Agenda Group members thought that the Applications research project ought to go ahead, but their decision meant that they would have to revisit the research-model question again.

This meeting of the Agenda Group illustrated several important aspects of the Center. First, its collaborative model, which extends across institutional boundaries, leads to arguments where the issues involve not facts but preferences and perspectives. This is precisely the value of a cross-institutional collaborative model, but that does not make it easy. Second, inherent in the Center's mission is a conflict between attention to technology and attention to education as practiced in existing institutions, and this conflict must remain at the Center's center lest its research become irrelevant to either arena. Third, firm

principles are both extremely useful in making choices within limits and also difficult to follow when general plans become specific.

The Connecticut Institute on Computing in Schools

The Center's first off-site Institute, in Vermont in January, drew an audience whose institutional affiliation varied -- half school people, about a quarter state Department of Education people, and the rest independent consultants or college faculty -- but whose knowledge of and enthusiasm for educational technology were uniformly high. The sessions, which reflected the Center's focus on subject matter, drew productively on the audience's expertise, and the general sense among participants was that the presentations and discussions helped move discussion of educational technology to a new and more useful plane. It also turned out that the participants were connected to most of the very tight Vermont networks (electronic, organizational, and personal) concerned with educational technology, so that the Institute's effect was likely to extend well beyond the participants.

We expected the April audience in Connecticut to have the same character. It was, instead, very different. One participant reported that her superintendent sent her in a last-ditch attempt to persuade her that educational technology had a place in schools. Several others reported that they were intrigued with but essentially ignorant of educational technology. There were very few participants whose knowledge of educational technology approached the Vermont Institute's average. Moreover, few of the participants knew each other, or much about each other's systems.

What was striking, in view of these differences, was the degree to which the Connecticut Institute's success matched that of the Vermont Institute. Toward the end of the two days participants reported that their thinking about educational technology had evolved to a useful plane, one -- like that reported by the Vermont participants -- which emphasized the importance of subject matter in thinking about educational technology. Much of the discussion in sessions was similar to that in Vermont. This was striking since it suggested that technological expertise was less important to high-level learning about educational technology than the conventional wisdom -- or at least our wisdom -- held.

In some ways, in fact, the Connecticut group dealt with more subtle issues than the Vermont group had. One widely ignored piece of educational technology, for example, is the video projector, which in addition to permitting classes to view videotapes or broadcasts also permits a session leader to involve an entire class in interaction with a piece of computer software. This can lead to group interaction and collective problem solving impossible with one microcomputer per student. The Vermont participants themselves did not use video projectors with any frequency, nor did they appear to regard our use of them in Institute sessions as an important part of our presentations. Without any prompting from us, on the other hand, the Connecticut participants spent a good deal of time discussing the ways a video

projector changed classroom dynamics relative to individual or small-group work, and this discussion then influenced the group's reaction to specific pieces of software and subject matter.

At the end of the Connecticut session, the last-ditch teacher reported that she had finally understood why people were excited about educational technology, and that her superintendent, by sending her to the Institute, had created a thoughtful -- and perhaps costly -- enthusiast. What we learned from the Connecticut Institute were three key lessons. First, there are large audiences with only rudimentary understanding of what educational technology is or does. This fact is easily forgotten by people, including us, who are interested in the field. Second, it is not necessarily true that technological competence must precede sophisticated thinking about educational technology. Third, a subject-matter emphasis provides a broad entry point to educational-technology training activities, one which is open to participants of varying expertise.

Methodology

Research proceeds differently depending on the clarity of underlying theory, the focus of the research question, and the relative interest of the researcher in hypothesis formulation and proof. There is remarkably little theory or prior research which speaks to the cognitive interaction between child and computer, or to the accuracy of computer representations of reality, or to the interdependence of context and medium in education. This led to early statements in Center documents that much early research would involve essentially ethnographic examination of a few instances of technology-based teaching and learning. As later sections of this document will make clear, things have not always worked out that way. Two research projects -- Word Problems and Weight/Density -- are cases in point.

The Word Problems group, coordinated by ETC co-Director Judah Schwartz, followed a particularly interesting path. Schwartz has strong views, based on a decade of research, about why word problems are so problematic, and about how the material can be taught more effectively. The essence of his view is that students ought to approach word problems by considering the units in which the various quantities referred to by the numbers -- both givens and desired results -- are measured or counted, since in many cases the relationships among quantities' units constrain and sometimes directly indicate the necessary operations. Teaching word problems therefore ought to involve an emphasis on the examination and manipulation of units. There exists software (including some from Schwartz's hand, not coincidentally) which emphasizes the role of units in calculation. Schwartz proposed that the Word Problems research focus on the ways unit-emphatic software might be used by teachers to teach students how to approach word problems. The methodological upshot would be studies focusing on how well the approach worked, and what seemed to foster and inhibit success.

The Word Problems group found Schwartz's proposal attractive but incomplete. Several of its members believed it was more productive to

teach students to classify word problems into a finite set of types, where each type entailed a particular reference setting such as rate-time-distance or base-part-percent. There is, as it happens, a long curricular tradition based on this belief. It implies that students have difficulty with certain word problems because they are unfamiliar with the relevant type, and that teaching more types is the way to teach word problems more effectively. The ensuing argument about whose view was right led naturally into two proposals: that the group see how familiar typical students were with different types of word problems, and that its teaching experiments not involve the assessment of one approach.

The result of the Word Problems discussion was research whose methodology had more to do with descriptive survey work and quasi-experimental comparison than it did with ethnographic documentation of a learning milieu.

The Weight/Density story is similar, but reversed. Sue Carey of MIT and Carol Smith of the University of Massachusetts at Boston, who have coordinated the group, specialize in the cognition of scientific phenomena, and particularly in the ways novices come to understand what experts are telling them. A key obstacle to such understanding is the absence of an appropriate model in the novice's mind, and a key way to facilitate understanding is to provide a model. In the case of weight and density, the requisite model might reflect the particulate nature of matter. Thus it seemed reasonable to the group that systems which let the learners experience a particulate model would be useful adjuncts to teaching weight and density. The group moved rapidly to a conception of two such models: a light styrofoam matrix into which heavy ball bearings could be embedded densely or sparsely, and a computer simulation which could present dots tightly or loosely clustered on the screen. In both cases the number of objects (bearings or dots) would represent weight, their degree of compression (or dispersion) density.

The proposed methodology entailed ascertaining children's understanding of weight and density, exposing them to one of the three teaching devices (large and small blocks of heavy and light metal, the styrofoam/bearing system, or the computer simulation), and testing their understanding after this exposure. This was the most classically designed of the Center's initial research projects.

The pilot research, with first, second and third graders, involved only the blocks and the computer. One of its purposes was to assess whether children find the computer problems easier than the block problems. It was hypothesized that the computer problems might be easier because dot crowdedness is a perceptually available intensive quantity, whereas density is not.

The results showed that children made more errors on the computer problems, but that these were due to using different strategies in the two problem situations. The block problem elicited qualitative strategies whereas the computer dot arrays led to attempts to quantify. Overall, the pilot work showed that for most children the core difficulty was not in differentiating weight and density, or in having a qualitative notion of intensive quantity, but in dealing with intensive

quantities more quantitatively.

As the Weight/Density research moves into its next phase, it is becoming somewhat less classical and somewhat more ethnographic, in that it is concentrating more on recording and analyzing what transpires and what children are thinking and less on testing particular aspects of particular approaches. This is the opposite of the Word Problems group's evolution, and illustrates the hazards -- and benefits -- of methodological specificity.

This Report

The Center out of which these stories emerge is just over one year old, the joint product of a series of discussions among the individuals and organizations that proposed it and a set of specifications, objectives, products, and resources in the form of a contract from the National Institute of Education. In the introduction to this first-year report we have tried to suggest, by example, the flavor of the Center's work and the kinds of questions and issues its work addresses. In the remainder of the document we will sketch, in relatively brief form, what the Center has done during its first year.

We will begin by discussing the Center's research projects. We will then turn to the Center's agenda-building activities, which relate closely to its research. Following this we will outline the Center's training, conference, and dissemination activities. We will conclude with a summary of the Center's plans for extension and expansion, of structural and substantive issues which continue to defy it, and of the products it expects to produce.

RESEARCH

Our focus in this document is on what has actually happened in the Center's research groups this year. We will devote little attention to the premises on which different groups proceeded or to the details of their research designs, both of which have been the focus of earlier documents (primarily the Agenda for Research dated March 1984, and available from the Center or from NIE). We will begin with the math Targets of Difficulty projects and continue with their science counterparts. We will then discuss the three computer education projects, which follow the Targets of Difficulty model less closely. We will then turn to new-technologies projects.

Fractions

From a classroom perspective, the problem of fractions and decimals is a problem of teaching a symbol system (e.g. decimal point, fraction bar), a complicated set of notational schemes (numerator and denominator, place value notation for both positive and negative powers of 10), and computational algorithms within those notation schemes. From the perspective of mathematics as a discipline, the problem of fractions and decimals is the problem of quantifying continuous quantity, and devising a symbol system and a notation scheme that encodes that quantification. From a cognitive-development perspective, the problem of fractions and decimals is a problem of reliably mapping the perceived properties of the continuous quantities being described onto the symbol system and the notation scheme, and vice versa.

A central thesis underlying this project is (a) that the notion of "betweenness", so evident in the perception of continuous quantity, is neither evident nor even salient in the symbol systems and notation schemes used to describe continuous quantity, and therefore (b) that this absence of clear evidence of the order properties of fractions and decimals contributes in an important way to the subsequent difficulties that students have learning to manipulate such numbers.

In order to examine this hypothesis, the word-problems group believes that a mixture of hands-on and microcomputer-based activities will be particularly helpful. It is designing a teaching experiment to explore the validity of the hypothesis. The pedagogy of the teaching experiment has four elements:

(1) measuring length using common objects as units;

(2) making and using fractional and decimal rulers with, for example, paper folding and rubber band stretching strategies;

(3) instantiating the ruler-makir ictivities on microcomputers and extending them to cases not possible with hands-on materials; and

(4) examining the understanding of "betweenness" within the notation systems for fractions and decimals using a series of microcomputer-based games that depend on the order properties of

decimals and fractions.

As part of its planning for the teaching experiment during the late spring, the group reviewed at length and in depth much of the available software dealing with order properties of fractions and decimals and "betweenness".

Software Review

Fraction Software. The software reviewed falls into two categories: (a) question posing embedded in games, and (b) expository material of a traditional sort. Since the focus of the group's effort is on order properties, the research group concentrated on trying to find usable pieces of software that addressed this concept.

Most of the relevant software available either concentrates on computations rather than in order, or involves game contexts that teachers judged to be so distracting (particularly in their use of irrelevant graphics or sound) so as to lose most, if not all, of their usefulness. A further difficulty with the existing fraction software, for purposes of this project, is the fact that so much of it deals with order properties either in terms of discrete referents or in terms of no referents at all. In contrast, the group's working hypothesis depends on the development of children's understanding of the order properties in the context of continuous referents.

Almost without exception, relevant fraction software does not distinguish clearly between one dimensional and more-than-one dimensional referents (that is, for example, between "5 out of 10 people" and "5 children per 10 families"). This presents a particular difficulty to the working group because of the centrality of the notion of "betweenness" -- a property of one-dimensional referents only -- to its work.

Two pieces of software were found to deal with the order properties of fractions in ways that seem to be useful to the group's purposes. These are Darts, written several years ago at Bolt, Beranek, and Newman by John Seeley Brown and his collaborators, and the fraction game in Number Quest, written by Judah L. Schwartz and his collaborators at the Education Development Center.

Decimal Software. The search for pertinent decimal software was both less extensive and less successful. First, there seems to be substantially less software dealing with decimals than there is with fractions. Second, most of what decimal software there is deals with computation rather than order properties. Possibilities for use of existing software need to be further explored.

As the working group examined available software in the area of fractions and decimals, it began to evolve a set of design notions for software that it felt could be useful. Two of these program designs were implemented during the summer of 1984 by a research assistant at ETC. Both of them deal with the ordering of fractions and are variations on

the card game commonly known as "Blackjack" or "21".

Pilot Studies

We anticipate that pilot studies will begin in late fall using the curricular design the group made during the spring, the usable existing software the group assembled, and the prototype software produced during the summer of 1984.

Early on, the group decided to defer the question of the grade level setting for the pilot effort until it could see what corpus of assembled materials it would have to work with. The reason for this decision was that student difficulties with the areas of fractions and decimals tend to persist well beyond the topics' introduction in the early grades, and that there is therefore ample reason to try materials of this sort as early as grades 3 and 4 and as late as grade 9. The working group is presently addressing the questions of the scale of the pilot studies and the grade-level setting for them.

Word Problems

From the classroom perspective, there is no part of the mathematics curriculum that is harder for teachers to teach and students to learn than word problems. Although mastery of computation seems to correlate with skill in solving word problems, there is ample evidence that computational mastery in itself is not sufficient to assure it.

From the perspective of mathematics as a discipline, the problem of word problems is the problem of modeling. How does one decide which elements of one's surround are pertinent to the set of possible quantitative relationships that can be asserted about the situation in question? From a cognitive-development perspective, the problem of word problems is the problem of recognizing prototypical situations for which a given tool is appropriate. The central thesis underlying this project is that difficulty with word problems reflects an inability to recognize appropriate correspondences between prototypical situations and useful mathematical sets of operations.

To explore this thesis, we have designed a three-stage experiment.

(1) Collect and classify student-formulated word problems according to taxonomic schemes extant in the literature for the classification of word-problems.

(2) See whether the categories of word problems students find most difficult correspond to the sparsely populated categories of student-formulated word problems.

(3) Devise "problem-webs" (explained below) in the empirically difficult categories.

If thi: effort is successful, it should be possible to detect a

change in the overall word problem-solving skill of students as well as in the pattern of situations they recognize and spontaneously offer as examples of settings corresponding to useful sets of mathematical operations.

The preceding analysis pertains to "one step" problems. There seem to be students who do not have difficulty recognizing and using any of the semantic correspondences discussed above, but who are nonetheless unable to design a solution to a problem that involves concatenating several such steps. Difficulty with planning, as distinct from recognition, may be the culprit here.

Spring Pilot Study

In the spring of 1984, the word-problems group conducted a pilot study designed to help it understand better the types of single-step word problems students found difficult. In order to do this, students in six classes, ranging from fifth to tenth grade, were asked to make up (but not necessarily solve) a series of five word problems. The first four problems were each to require the use of a single arithmetic operation, and the fifth could take any form.

Several hundred student-generated problems were collected in this fashion. Unfortunately, the elicitation of the problems from the students was not done crisply enough (students were asked "make up a problem that requires multiplication" rather than "make up a problem that requires only one multiplication and no other operations"). As a result, a large fraction of the student-generated problems were multiple-step problems, and therefore only indirectly useful for the understanding of single-step student difficulties.

It was nonetheless possible to classify a sufficiently large number of these problems to confirm, at least provisionally, the hypothesis that the student-initiated problems would fall into the categories that have been reported in the literature as difficult for students. Specifically, fewer than 5 percent of the student-initiated problems in subtraction were of the comparison type ("Jack has five apples, Joe seven. How many more does Joe have?") while over 90 percent were of the cause/change type ("Joe gave Jack two of his seven apples. How many does he have left?"). Similarly, except for some area-measurement problems, students offered neither Cartesian product (Extensive x Extensive) problems nor any related rate (Intensive x Intensive) problems.

Fall Pilot Studies

Problem generation. Because of the difficulty of interpreting some of the data from the spring pilot study, in the fall of 1984 the group redid the study of student-generated problems. This replication focused on multiplication and division problems, where the data from the spring study were hardest to interpret. A total of 562 word problems were collected. The problems were classified by problem type, and by the student's grade, age, sex, mathematical ability as assessed by the

classroom teacher, and community (school district).

Of the problems generated in response to the multiplication prompt, 84 percent were single-step word problems. Of these, 84 percent were Intensive x Extensive and 16 percent were Extensive x Extensive problems. There were no Intensive x Intensive (related rate) problems nor were there any Cartesian products other than area measurement. Of the multi-step problems, most in the lower grades posed no question and most in the higher grades involved multiplication and addition.

Of the problems generated in response to the division prompt, 90 percent were single-step word problems. Of these, 83 percent were Extensive/Extensive and 17 percent were Extensive/Intensive problems. There were no Intensive/Intensive or Intensive/Extensive problems generated.

Of the multi-step problems, most were subtraction problems in the lower grades. Children of higher ability and in the higher grades tended to generate a higher percentage of single-step problems than did the others. Problems that posed no question for the reader were frequent only in grades 4-6. Multi-step problems came mostly from those of lower ability. There were no differences in any respect due to sex.

Problem difficulty. This study involved asking about 500 students in grades ranging from 4 to 12 plus first year college to indicate for each of 11 word problems the arithmetic computation they would use in order to solve the problem. The data collected in this study are being analyzed along the same lines as the data collected in the first study. Of central importance is the correspondence between the distributions of problem difficulty in the two studies.

Problem Webs

The strategy this group will employ to help students do word problems more easily is to generate "problem webs", particularly in those problem categories that are difficult for the students. This strategy stems from the hypothesis that for any single-step problem type, however difficult, there is a setting with familiar enough referents and congenial enough numbers that most students will be able to solve the problem with little difficulty. For example, consider the following problem: "If there are 2 candies per bag and you have 3 bags, how many candies do you have?". The problem is structurally identical to "If there are M X's per Y and you have K Y's, how many X's do you have?". Few children will have difficulty with the first problem, yet even most adults will have difficulty with the second one.

The question then arises "Is there a way to modify sequentially the harder problem, at each step making its elements more familiar and congenial, and all the while preserving its structure, until one arrives at the simpler problem?". The pedagogical implication, following Polya, is to teach students that when faced with a problem which seems too difficult, they first should formulate a simpler but similar problem and solve that. Formulating a set of related problems can be thought of as

an act of building a theory of problem difficulty within a given problem type. There is no particular reason to assume that there exists a unique well-ordered sequence of problems from the first problem to the second. Rather, it is possible to formulate a web of problems that lead from the first to the second along many different trajectories.

The dimensions along which one chooses to modify the problems are clearly of key importance in the design of problem webs. The group has begun building a web for the intensive x extensive problem structure, limiting itself initially to the exploration of discrete referents. This has the obvious consequence that the numbers the problems employ will be integers.

It is important to point out that the dimensions along which the problem web is constructed are thoroughly conjectural in nature, and that the degree to which they map the topology of problem-difficulty space as perceived by students, as well as their pedagogic utility remain to be confirmed empirically. The group plans to do exactly this by having students rate unordered sets of problems drawn from the web according to their degree of difficulty.

Heat/Temperature

This study is designed (1) to explore the reasons students find the concepts of heat and temperature, and the differences between them, so difficult and (2) to devise technology-based instructional materials that may alleviate some of these difficulties. The study employs a set of pre-tests designed to diagnose students' spontaneous theories about thermal phenomena, followed by a specific course of instruction designed to clarify students' understanding of heat, temperature, and the distinction between them. Post-tests assess whether the students' theories after the instruction are different from their pre-instruction spontaneous conceptions.

Pilot research was conducted during the spring and summer to develop effective pre-test and post-test procedures. The group also pilot tested materials to be used in the instructional phase of the research.

Measures

To develop the pre-test and post-test, 18 students ranging from 9 to 15 years old and five college students were interviewed and observed individually as they puzzled over two thermal demonstrations. One demonstration explored the effects of heating on the volume of a liquid, the other the effects of cooling.

In the first case, subjects were asked to predict what would happen to the level in a flask of colored alcohol when the flask was placed in a hot-water bath. Subjects' predictions and their responses to the observed phenomena were probed to clarify their spontaneous conceptions of thermal dilation. Subjects were then asked questions like, "What would happen if we add hot water to the bath?"; "What would happen if we

use hotter water?" Answers to these questions were pursued to uncover notions of thermal equilibrium, of specific volume as a function of temperature, and of the differentiation between heat and temperature.

When the subject's understanding of these concepts had been explored fully a second demonstration was introduced. This was parallel to the first, but used ice instead of hot water. A thermometer was placed inside the flask of alcohol and the flask was set in a container of crushed ice. Subjects were asked questions like "What will the thermometer readings be after one minute, one hour, one day?"; and "What would happen if we added ice around the flask?". Subjects were asked to make and explain observations in order to reveal their notions of the differentiation between heat and termperature, the nature of cold (whether they conceive it as the absence of heat or as a quality that is the opposite of heat), freezing points, and thermal equilibrium.

The results of these interviews are being analyzed with several issues in mind. First, do the demonstrations and interview questions reveal students' conceptions of thermal phenomena? Second, if so, what are these conceptions? In examining these questions the group is comparing the notions of naive subjects with conceptions of thermal phenomena that were prevalent at various periods in the history of science. They hope this comparison may point both to features of common misunderstandings and to experiences that stimulate subjects to develop more modern conceptions, i.e. phenomena that contradict their assumptions.

Preliminary analysis suggests that the interview is a useful tool for investigating students' conceptualization of thermal phenomena, except possibly for the younger subjects, 9 to 12 years old. Results were rather different for high school students in two different towns and for high school and college students within the second town. High school students in the second town had the best understanding of modern thermal physics, better than college students in the same town. This might indicate that the high school students in the second town had a more recent encounter with the topic or a different curriculum from those in the first town. It also might indicate that modern thermal physics, even after once learned, "disappears" over time while the na've theory re-emerges, perhaps because the spontaneous theory makes more sense to the individual. A longitudinal study may be useful for investigating this question.

While students varied greatly in their predictions and explanations, there were some common themes in their comments:

(1) Students never talked about nor reasoned in terms of <u>amount</u> of heat.

(2) Even students who stated that "cold is absence of heat" did not make use of this idea in their descriptions of the cooling phenomena, suggesting that cold is more easily viewed as an entity in its own right rather than as the absence of heat.

(3) Many students had learned that heat increases the motion of the

molecules and explained dilation in those terms. But later in the interview, many referred to the heat pushing the level up. Their language suggests that sophisticated microlevel interpretation of the phenomena coexists with a more spontaneous interpretation in terms of direct, causal, macrolevel force or pressure.

(4) While a significant number of students invoked thermal equilibrium in their explanations, their explication was different from a modern physicist's account. It was based on the idea that sources of heat/cold apply their heat/cold to the flask and its contents and obviously cannot make them any hotter/colder than they are themselves.

(5) While analysis of the interviews is not yet complete, preliminary results strongly indicate that students do not adequately differentiate heat and temperature. They all said that thermometers measure heat and that the difference between heat and termperature was that temperature encompasses the cold end of the scale.

(6) Students evince beliefs that are consistent with early models of thermal phenomena, either coexisting with or existing in place of modern physics notions. Further analysis will examine the interactions among models within individual students.

(7) Early models of thermal phenomena appear to be a valuable guide in analyzing the thermal theories held by novices. The demonstrations, questions, and challenges, incorporated in the pre-test activities appear to be useful in clarifying subjects' conceptualizations.

Instruction

The instructional phase of the research will use a set of specially designed equipment, including special purpose hardware interfaced to microcomputers, that will give students direct phenomenological access to both heat and temperature in ways that clarify the difference between them.

One member of the project team, Robert Tinker, has designed in his work at Technical Education Resource Centers (TERC) temperature probes, heat pulse generators, and programs which permit these devices to be interfaced with microcomputers to display temperature and heat input graphs as functions of time. The programs also permit calculations to be made on the heat and temperature data. Graphs of different "runs" can be compared to study temperature changes in various liquids when they are heated. The programs also generate visible evidence that temperature does not change during boiling even though heat is being delivered to the liquid. The programs are well suited to the study of specific heat and phase change.

This equipment was pilot-tested with students in the eighth grade. Students were allowed to experiment freely with hardware and the

program. These studies indicated that the students understood the mechanics of the software and the meaning of the visual displays.

This equipment, which is leased from TERC by ETC, will be used as part of experimental lessons designed to help ninth graders distinguish heat and temperature. Students will be given a series of problems illustrating principles of specific heat and the thermal phenomena associated with changes of phase. Students will solve the problems by working with the computerized heat pulse generator and temperature probe. Pilot versions of the experimental lessons were tried out with ninth grade students during the spring. These studies indicated the need for a more powerful heating device and for more numerous and varied experimental situations in addition to those planned to demonstrate specific heat and changes of phase.

The research team is currently reviewing the results of pilot work and making the indicated revisions in the pre- and post-tests and in the experimental equipment and activities. It is also refining the observation methods for the experimental lesson. Once these aspects of the experiment are determined, the team will train two ninth grade science teachers to carry out the experimental lessons with their classes. The teacher's role in the experimental lessons will be carefully structured to help students analyze the phenomena they are witnessing in ways that clarify distinctions between heat and termperature. Researchers will record the interactions during the lesson in order to understand whether the lessons are effective and, if so, what aspects of the lessons appear to be most salient.

The group plans to conduct the study (pre-test, instruction, post-test) in three classrooms this winter. If the results are encouraging, the team will carry out more tightly controlled experiments with a larger sample of students.

Weight/Density

This project explores the reasons for students' difficulties in understanding the concepts of weight and density and the merits of various strategies, some involving computer simulation, for helping students overcome these difficulties. The project focuses on students' conceptions of density as an intensive quantity and on ways in which students acquire a particulate theory of matter.

There are at least two possible explanations for students' difficulties with the notion of density. The difficulty may stem from a limited physical theory which does not enable students to conceptualize objects as composed of discrete particles of matter and therefore precludes a clear model of density. Alternatively (or perhaps in addition), the problem may be that density is an intensive quantity whose representation requires coordinating and manipulating two quantities (size and weight). This research team conducted pilot studies last spring and summer to determine the relative contributions of these two possible sources of confusion and difficulty.

The pilot study presented subjects with two parallel sets of problems in counter-balanced order. One set involved cylinders of steel and aluminum of varying sizes and weights. The other set involved computer-generated arrays of dots, of varying areas and dot densities. In the computer-generated arrays, the area covered by the dots, the number of dots, and the crowdedness of dots served as analogs of size, weight, and density respectively. The arrays contained two different levels of dot density: the more crowded dot arrays were always green, while the less crowded arrays were always purple.

In each problem set, the tasks were the same. Subjects were first given experience comparing the weights of differently sized objects made of steel and aluminum, and of comparing the number of dots contained in differently sized arrays of green and purple dots. The purpose of this initial experience was to give subjects an opportunity to become familiar with the experimental materials, to learn that steel seems a heavier kind of stuff than aluminum, and to learn that arrays of green dots are more crowded than purple ones.

Then, for the steel/aluminum problem set, subjects were shown a variety of pairs of steel and aluminum cylinders. In some cases both members of the pair were made of the same material, while in other cases, they were made of different material. In some cases, both objects were the same size; in other cases, they were different. In all cases, the subject was asked whether the two objects could possibly weigh the same. To predict weight successfully, students had to coordinate information about the size of the object with information about the density of the material from which it was made (the steel and aluminum cylinders were easily distinguished by their appearance). The interviewer probed to discover the reasons underlying the subject's judgments, and at the end of the task, asked the subject under what conditions a steel and aluminum object could weigh the same.

A parallel procedure was followed for the computerized dot arrays. Subjects were shown outlines of two separate areas. Sometimes the areas were equal, sometimes they were different, sometimes the outlines were of the same color, and sometimes they were different. In each case the subjects were asked whether they thought it possible that the two arrays had the same number of dots in them (when they were filled in). For these problems, students had to coordinate information about the size of the array and about the dot density (based on the color of the outline) to predict the number of dots the array would contain when filled in. Again students were questioned to discover the reasons underlying their predictions.

The research team was particularly interested in determining which type of problem -- the cylinders or the computer analog -- was more difficult. They hypothesized that if a non-atomistic physical model were the major source of confusion, then the computer analog, which presents an atomistic model, might be easier. In this case, the group supposed that the computer analog might be used as part of a teaching intervention to help students make the weight/density distinction by recognizing the dot array as a model of the structure of matter. If, on the other hand, general confusion about intensive quantities, regardless

of any implicit theory of matter, were the major root of difficulty, then the two problem sets might be equally difficult. In this case, attempts to teach the weight/density distinction might better focus on teaching students about intensive quantities.

Pilot research using the two problem sets was conducted with ten first graders, eight second graders, and ten third graders from two different middle to upper-middle-class suburban settings (one a school, one a day camp). The results indicated that for every age group the steel/aluminum problems were easier than the computerized dot array problems, and that the majority of second and third grade subjects showed some understanding of both types of problems. There were also indications that the two problem sets elicited different strategies, and that greater numbers of errors on the computer problems reflected students' attempts to apply more sophisticated quantitative strategies in solving these problems. Further analysis of these results will be necessary to clarify the strategies children used and to explore whether the computerized dot arrays might be useful in helping students consolidate and extend their emerging understanding of weight and density.

The research team is currently analyzing the results, both quantitative and qualitative, of the pilot research in order to understand better the reasons for student errors on both types of problems and the nature of the conceptions underlying their responses. It plans to conduct additional pilot work this fall, to include different populations of subjects and different types of experimental problems, to clarify issues, and to investigate methods for helping students develop robust theories of density. Based on these results, it will plan a teaching intervention to be carried out in the spring of 1985.

Scientific Theory and Method

The focus of this group (called "hypothesis formation" in earlier reports) is to help students understand the scientific method and the nature of scientific theory. Its approach is to engage students in "doing science" by having them construct scientific theories on their own to account for data they observe. Students focus on a question that needs explanation, and proceed to make and record observations of relevant phenomena, organize data that they collect, look for regularities, form hypotheses to account for their observations, use inference to predict future occurrences, test their hypotheses by making further observations, and revise hypotheses in light of counterexamples. The group intends to focus students' attention on the difference between observations of natural phenomena and the theories that scientists develop to account for the phenomena they observe. The project reflects a belief that understanding the relationship between data and theory in scientific work is important not only for the training of research scientists but also for a general lay understanding of scientific information.

To date the group's work has focused on devising ways of permitting

students to "do science" on a small scale that is feasible for novices and that highlights the general procedures of scientific method. The difficulty has been that many scientific phenomena are not studied easily through controlled experiments that can be reasonably conducted in school classrooms and teaching periods. Many experiments considered by the group were found to be plagued by such problems as excessive duration, costly equipment requirements, or dependence on infeasibly controlled environments. Others were judged as lacking content of particular interest or appeal to students.

The group's review of possible experimental situations has led it to settle on four approaches to teaching scientific method. With each approach, students will go through the steps in the scientific process described earlier. The teacher's interventions and the students' responses will be monitored in a pilot study to gauge the effectiveness of the different approaches for enabling students to derive scientific principles and to construct theories. Students will be evaluated on their abilities to understand what constitute relevant data in a given experiment, to form and test hypotheses, to make inferences and revise hypotheses, and to derive theories that explain the observed data.

The questions this study will address are three:

(1) Will students' understanding of scientific theory be enhanced by "doing science"?

(2) What kinds of theory-building activities are effective with students?

(3) Does student ability to engage in hypothesis formation and testing improve with different experimental approaches, and does it transfer from one approach to another?

The four experimental approaches are:

(1) Computer simulations of natural phenomena. Two examples are a piece of software called Race Track that illustrates principles of force and acceleration, and one called The Scientific Method that simulates controlled experiments with the rate of crickets' chirping. These programs permit the user to vary a limited number of independent variables and to observe the effect of these variations in a closed system. In effect, the programs allow users to develop and test hypotheses about the particular system by performing multiple simulated experiments.

(2) Experiments with natural phenomena that do not involve physical materials. Here students will use data from their own language to derive linguistic principles. One advantage of linguistic material is that students can collect data, form hypotheses to account for the data, test the hypotheses by searching for counterexamples, and revise and retest the hypotheses without requiring any special equipment or materials. Furthermore, linguistic data are less sensitive to environmental conditions than are data from physical experiments. The group is developing exercises for deriving

linguistic principles regarding the formation of plurals and the formation of "tag questions" (questions formed by adding a phrase to a statement — for example, "He left the room, didn't he?").

(3) Computer-based systems that require hypothesis formation and testing, but are not based on natural phenomena. Such programs present puzzles of different sorts for solution, and the user must derive the principles that explain the particular system. Examples are The King's Rule and Truth about Tribbles.

(4) Experiments involving manipulations of physical objects in the natural world. Possibilities being considered for this part of the project include experiments involving a pendulum, the viscosity of liquids, and the absorption rates of different substances.

The group has reviewed available software to use in approaches 1 and 3. The linguists in the group have drafted materials for approach 2. The science teachers in the group are working on experiments for approach 4. The entire group has critiqued all materials. In addition to this work on developing materials, the group is clarifying its research design and developing assessment procedures for use in the pilot study.

Pilot research will be conducted with middle-school students for each of the experimental approaches as soon as materials are completed. Pilot work with approaches 1, 2 and 3 will begin this winter and will be completed by next spring. Pilot work with approach 4 will be undertaken when materials are ready. Results will be analyzed and, if appropriate, synthesized into an experimental curriculum suitable for a teaching experiment with seventh through ninth graders.

Complex Systems

Many scientific phenomena that students ought to understand involve interactions among many variables. Moreover, many of these phenomena derive from natural systems students cannot readily manipulate. Therefore, what students typically learn about complex systems is an intuitive aggregation of what they learn about several underlying bivariate systems. This is often inadequate.

Computers and related technologies are capable, among other things, of running programs which simulate the behavior of complex systems, provided the behavior of such systems can be summarized as a set of equations. This group's basic interest is in the potential use of technology to teach students about complex systems. This interest expresses itself in a range of questions concerning the structure of simulations, their role in the classroom, what "understanding complex systems" means, the correspondence between simulations and reality, and so on.

After prolonged and often difficult discussion, the group decided to begin work with an inquiry into some specific questions about learing from simulations versus hands-on experience. This required some

compromise, since few of the systems the group originally had in mind -- ecosystems, weather and acid rain, economies -- permitted hands-on study. The focus of the initial study had to have two key attributes: (1) it needed to be small and simple enough to permit students to experiment with it directly, and (2) it had to be complex enough to represent the complex systems in which the group was interested.

The group decided, after further difficult discussion, to focus initially on two systems: helium balloons trailing very long strings, and leaky containers being replenished by steady streams of liquid. It decided, further, to focus initially on one attribute of these simple-yet-complex systems: whether and at what point they reached equilibrium. In the case of balloons, equilibrium depends on the lift of the helium relative to the weight of the string; in the case of containers, it depends on the loss rate (a function of the contents of the container) compared to the replenishment rate.

Thus far the group has conducted a series of pilot studies designed to specify the key elements of the balloon systems and to gather preliminary data on children's understanding of them. This has involved two activities. The first activity was extensive experimentation by researchers with the balloon system, to decide what the key elements in its equilibrium are and to refine the system's elements. The second was qualitative, open-ended analysis of several children's explanations of why the system reached equilibrium, how its equilibrium point could be changed, and what the effect of specific changes -- such as cutting the string, or adding a second balloon -- might be.

The next steps in this group's work are (1) further work with the real balloon system, (2) parallel work with the container system, (3) further development of simple computer simulations which mimic the effect of key variables on each system, and (4) comparison of students' reactions to real and simulated experiments.

Machine Handling

The machine handling group ("functional models" in earlier reports) is investigating students' difficulties with computers aside from those difficulties arising from programming itself. Such difficulties include, for instance, starting and stopping a system, distinguishing what mode or level one is "in", and handling the routine mechanics of a text or program editor properly. These stumbling blocks interfere with the practical use of computers in many applications. They may also foster the notion that computers are mysterious and intractable, and create a psychological barrier to approaching computers and exploring their potential.

The group has proposed that teaching learners a few relatively straightforward mental models will reduce these difficulties. In order to assess what difficulties are most common and persistent for beginners, group members observed children learning Logo and Basic over the summer. This fall and spring they will observe children using computers in other applications, such as word processing or laboratory

tools. Based on these observations, they will develop and test some instructional mental models for children in grades four through ten.

The summer observations used a clinical approach: the observer noted the problems that students encountered and asked questions designed to probe the students' underlying concepts. Careful notes were taken on each observation, and case studies were later prepared. One to three observations were made on each of 30 students 8 to 16 years old attending Boston Museum of Science computer classes or a summer-school program at Newton, Massachusetts, including computer and other activities. These observations were the same ones used to investigate programming difficulties (described below), but machine handling problems were noted and considered separately.

Analysis of the summer observations has focused on the frequency and severity of six categories of machine-related obstacles commonly faced in learning to program. Five of these were identified last spring by the group, from teachers' reports; a sixth emerged during analysis.

(1) Memories and moves. Children were commonly confused about the several kinds of memories that computers use -- RAM, ROM, disks, and so on -- their special roles, and the options for moving information from one storage place to another. With experience, they learned rituals for the situations they needed to handle, but their understanding of the nature of these elements may have remained undeveloped.

(2) Commands, data, program, and interpreter. Students received little instructional guidance about these elements, and may never have come to understand what an interpreter is or that they were always interacting with some sort of program running in the computer. While their lack of understanding did not interfere with their elementary programming activities, it would probably inhibit further development.

(3) Operating levels and modes. Reports from teachers led the group to believe that difficulties in this category might be common. In the observed settings there was no opportunity to see children loading their systems, but there were clearly difficulties in moving among the Logo editor, immediate, and run modes.

(4) Starting and stopping. The process of starting up a system or piece of software and the process of bringing a session to a halt generated some confusion during the learners' initial encounters with computers and programming, but these were only transient.

(5) Locus of errors. In terms of machine handling only, learners rarely went awry through misclassifying the source of an error -- hardware errors including faulty disks, user errors, or errors in software. Misattributions were more common during programming activities, and these are being considered separately by the Programming group.

(6) Text editing. Difficulties in this area were both persistent and

severe. Despite extensive experience, many students never came to understand the logic of text editors they were using, nor how to use these editors efficiently. This distracted students from programming processes per se, and is also being addressed in the Programming group.

The group has also begun to develop mental models that might help learners to deal with the most significant problems of machine handling. For initial attention it has selected memories and moves, operating modes, and text editing. The instructional approach encouraged students to view the systems in question as designs adapted to their purposes, a style of presentation that the group believes fosters a better understanding and appreciation of the systems themselves and the human inventiveness underlying them.

(1) Instruction in memories and moves. Using simple diagrams representing disk, screen, RAM, and keyboard, the teacher illustrates features of the flow of information. These elements are also identified in a microcomputer with the cover removed to display the RAM chips. The students hear about the functions and tradeoffs of these components and how they operate as a team. In describing the flow of information with diagrams at the blackboard, the teacher not only describes the flow, but also enacts it. The teacher, for example, copies a sentence initially inscribed on the disk diagram to the RAM, not erasing the text on the disk; the teacher then makes modifications on the version in RAM not mirrored in the disk version. Once basic concepts are grasped, other components such as ROM, and input/output channels such as modems or printers will be added. The students will do a series of "what goes where" exercises to extend and reinforce their understanding.

While the diagrammatic modeling could be done with higher technology, for example by computer graphics display, the group currently does not see advantages to this presentation. On the contrary, the group expects that use of the blackboard and paper and pencil operations will make the concepts more accessible.

(2) Instruction in operating levels and modes. The mental model suggested for this area is based on a combination of spatial and personal analogies -- imagining you are moving about a building that has various workshops in it. Certain workshops have entrances to certain others. In each workshop is a robot that will do your bidding if you ask it in the right language. This metaphor aims to illuminate three confusing characteristics of operating levels and modes: that each one has its special purposes; that certain modes are accessible only from certain others; and that each mode characteristically has its own language. In practicing this model, students will make maps of systems they are working with as a series of workshops, and then do "where are you" exercises, using the prompt characters on the screen as clues. These exercises can be done on paper or by students working with computers in pairs, each in turn looking away while the other puts the computer into a mode or level he or she must then discover.

While better integrated systems, such as Boxer, may in the future do away with mode confusions, these will probably not be in use for some time. The group believes that present machine-handling problems can be remedied rather readily. Consequently it proposes that a modest amount of effort in resolving such problems is warranted.

(3) Instruction in text editing. Here instruction will provide students with a sound mental model of what they are really manipulating -- strings of text. Students will learn about the "invisible" characters blank and carriage return, and do simple translation exercises. They will be given a screen layout of a little text and rewrite it as a character string, and vice versa. The students will then learn to think of basic text editing moves such as insertion or deletion in terms of the character string model, and later about more sophisticated features of the particular editor they are using.

During this academic year the group will test these instructional models. It also will observe more varied contexts of computer use by elementary and high school students in order to check and revise present conclusions. The lessons will be tried out in small groups of students in grades 4 through 10 who are taking first courses in Logo or Basic. After revisions, the lessons will be offered to introductory classes in ETC-affiliated schools. Performance on the exercises, as well as observations and interviews after two weeks, will determine the success of the lessons. Depending on their success, the lessons will be either revised further or prepared for publication and dissemination.

Programming

This project addresses three research questions:

(1) What are the nature of the difficulties students encounter in learning to program and the factors that contribute to those difficulties?

(2) What strategies do students find helpful in overcoming programming difficulties, and what circumstances help students discover and apply those strategies?

(3) What, if anything, do students acquire from learning to program that might transfer to other contexts?

The pilot research conducted by this group addressed the first and to a lesser degree the second question. The group's principal research activity during the summer was conducting a series of observations and interviews with students learning to program in Logo or Basic. They observed children in two educational settings, a program at the Boston Museum of Science and a Newton, MA summer school program. In both of these settings children were learning Logo or Basic. The children studying Logo ranged from 8 to 12 years old and those studying Basic from 10 to 16 years old. Each child worked alone or with another student

at the computer.

The research technique was a combination of observation and clinical interview. The researcher sat with a student or pair of students as they worked, observed what happened, and asked questions designed to prompt explanations of the students' actions, to clarify the nature of the problems they encountered, and to examine the strategies they applied in trying to solve problems. Initially the researcher's questions were designed to clarify the student's thinking. As the interview progressed, the researcher might probe by asking questions designed to help the student diagnose or solve the problem at hand. These questions were intended both to clarify the student's spontaneous conceptions and to explore the sorts of interventions that might help the student overcome typical programming difficulties.

After each observation and interview, the researcher reviewed field notes and prepared a case study summarizing the problems students encountered, their spontaneous efforts to solve the problem and their explanations of these actions, and their responses to interventions from the researchers. The project leader met weekly with the research assistants to discuss their field experiences and analyze their case studies. The focus of these discussions was to discover patterns in the field observations and the case material which pointed toward a model of programming difficulties.

Over two months of gathering and analyzing data, the research team proposed some categories of behaviors associated with programming. They identified particular difficulties associated with each category and, in some cases, tentative hypotheses about factors that contribute to those difficulties. Through their efforts to ask helpful questions, they also developed some preliminary notions about how to help students overcome difficulties.

The preliminary list of categories -- which do not represent a series of steps that the programmer follows in chronological order -- has eight entries:

(1) Problem acceptance. Learners very commonly reject problems completely, skip to other tasks, or ask for help. Failure to accept problems appeared to reflect two factors: inability to discern a solution and general lack of interest and confidence. These findings suggest that affective and personality factors, as well as cognitive skills, influence the learner's response to programming instruction.

(2) Goal formation. A programmer must develop a mental representation of the program's overall desired performance. One frequent difficulty in this category, goal slippage, involves failure to respond when the program's performance is not what was originally intended. Preliminary findings suggested four mechanisms of goal slippage: (a) changing the goal, (b) ambiguous goal representation which allows for a faulty outcome, (c) failure to accept the original goal, and (d) failure to notice a discrepancy between the original goal and the actual performance of the program.

(3) Program planning. A programmer must plan the organization, flow of control, and data structures needed for a particular programming task. A common difficulty here may be called "template-bound planning". Students fit the problem to a simple scheme already in their repertoire, rather than develop a new or synthesized approach by piecing together several programming schemata. Nearly every student observed during the pilot research seemed template-bound.

(4) Coding. Coding refers to the actual writing of code in programming language. A common difficulty, seen frequently when students were trying to repair a bug in their programs, was that inserted or modified code revealed a starkly wrong conception of , primitives, or flow of control for instance. At least two mechanisms seemed to mediate these puzzling (to the observer) repairs: (a) inappropriate generalization from a single case the student had encountered previously, and (b) misinterpretation of program statements according to meanings suggested by surface features of the code.

(5) Code checking. Programmers must read back or step through code, either mentally or on paper, to check whether the code they have written has its intended effects. The group found two kinds of difficulties here: (a) not checking at all, and (b) inability to read back code and recount accurately what it does.

(6) Program testing. Program testing refers to running a program to test whether it is functioning properly. The principal difficulty identified so far has already been discussed, namely goal slippage.

(7) Diagnosing. Programmers must isolate and explain program bugs, preparatory to fixing them (the fixing itself falls under planning and coding). One difficulty observed here can be thought of as the lack of effective diagnostic strategies, e.g. inserting print statements to extract information about a program's behavior. In addition, beginning programmers often have trouble reasoning backward from the program's misbehavior to the offending bug.

(8) Inputting/editing. A common difficulty here is that many students, even after considerable experience, demonstrate persistent misunderstandings of and clumsy practices with the editor. While these difficulties exacerbate programming problems, they are actually machine handling problems that will be investigated by the group focused on that set of issues.

In the next several months, this project's principal aim will be to refine, revise, and extend this emerging model of programming difficulties and their causes. To this end additional observations and clinical interviews will be conducted in several classes where beginning programming is being taught. As the model becomes clearer, the group will design a set of programming problems to use for more structured research. These problems will be presented to students who will be observed and interviewed according to a structured protocol designed to test the accuracy of the model of difficulties and the efficacy of preliminary hypotheses about effective strategies for helping students

overcome these difficulties.

Applications

Recent definitions of computer literacy by computer education experts stress the role of the student as user of the computer rather than as recipient of computer based instruction. This definition naturally suggests the use of applications programs that are now available, such as word processing, databases, spreadsheets, instrumentation (data collection via computer), telecommunications, graphics production, music generation, modeling, and simulations. Student learning through computer applications programs has two aspects: learning about computers and their uses, and using a more powerful tool to address and manipulate subject-matter content. The use of applications programs could, in fact, fundamentally change the way in which certain subjects are taught and learned.

While a growing interest is reported among educators in teaching applications programs, and in integrating computer applications into math, science, language arts and social studies classes, there is very little information about their actual use. To address this lack, this group has begun a research program with three goals: (1) to investigate how teachers are now using applications, and how they are being integrated into the curriculum; (2) to identify difficulties in the use of applications programs that are commonly faced by both teachers and students; and (3) to consider the design of model curriculum units using applications software. Research activities this year have addressed the first two goals; the group has conducted a survey of teacher's use of applications programs in the greater Boston area, has interviewed eight teachers who have developed curricula incorporating them, and has observed teachers learning applications programs in a training workshop.

Survey

Survey results reveal a variety of instructional orientations and uses. Questionnaires were given to 200 teachers judged likely by district representatives to be using applications software . The 71 respondents included about equal proportions of teachers in elementary, junior and senior high schools. About two thirds reported that they used computers for "teaching and learning" (drill and practice, tutorial use, and simulations). An equal percentage used the computer as a subject of instruction (introduction to computing, programming, and computer science); and a somewhat greater percentage (76 percent) indicated that they used computers as a "student tool" (word processing, data analysis, laboratory experiments). Elementary school teachers were more likely than those at other levels to be teaching computers as a "subject of instruction." The most frequently cited specific uses included word processing (cited by more than 70 percent of the teachers), concept demonstration (54 percent), simulations (52 percent), instructional games (51 percent), and drill-and-practice (50 percent).

Concerning the teachers' access to computer resources, 18 percent

had no computer or terminal in their classroom, 44 percent had one, and 16 percent had two. Seventy-five percent had access to computers in a lab. Forty-four percent felt that their access to computers was "inadequate", with no significant differences across grade level.

In contrast to the feeling of inadequate access, 90 percent reported that student interest was "adequate", 78 percent reported an adequate level of administrative support, and 63 percent perceived adequate teacher and staff interest in computers. Areas seen as "inadequate" included "quality of software" (63 percent), and integration with the rest of the curriculum (61 percent). No significant differences were observed across grade level on these points.

Observations and Interviews

Questionnaire respondents who appeared most likely to have extensive information on classroom use of applications software were selected for interviewing, and included classroom teachers as well as computer specialists. All taught in relatively affluent suburban school districts: five at the elementary level, two at junior high, and one at senior high. Except for two, their experience was limited to the past year. The interviews included in-depth information about the role of the teacher in computer education at the school, the history of the teacher's experience with computers and with particular applications software, and problems of students in using particular software. When questioned about "problems" that they observe in students use of software, teachers mentioned several kinds of difficulties. Significantly, however, no teachers considered these to be major problems.

In July, three researchers from the group observed 11 teachers learning to use Applewriter II, PFS File, and Visicalc at the Cambridge, Massachusetts, Schools Applications Software Curriculum Project. Half of the teachers had used other programs before, and the others had little or no experience at a computer. The observation format focused on the specific nature of problems that the teachers encountered while using the software, their apparent antecedents, and their solution.

Taxonomy

On the basis of the interviews and observations, the group has prepared a preliminary taxonomy of difficulties in use of software by teachers and students. These categories will be expanded and revised as additional observations of student use in classrooms are carried out in fall 1984 and spring 1985.

(1) Keyboarding. Locating keys and understanding special uses such as control key operations are a basic category of difficulties.

(2) Computer concepts. Difficulties also exist in understanding how the computer works, including the different kinds of memory, the importance of the data lines, and the importance of the cursor and

its location.

(3) Operations within specific programs. Cursor and page movement, saving and accessing files, and how to get online help are crucial aspects of program operation which may cause difficulties.

(4) Information management. This includes both the understanding of and use of information; it includes several elementary issues such as the use of consistent terminology, the planning and organizing data so as to allow for retrieval and difficulties arising from inadequate knowledge of the subject matter of a particular application.

(5) Attitudes and motivational factors. Perseverance, enthusiasm for new problems and for computers, and willingness to experiment arise here as a significant category.

(6) Organizational constraints. These are difficulties or constraints concerned with the number, type, location and availability of hardware and software, classroom composition, and organizational support.

In analyzing the information from the survey, interviews, and observations, a major task arose that was not fully anticipated and which constitutes an additional kind of finding of the work so far. It became clear that the terms people use to describe their use of computers and applications software have varying meanings. The meanings of many computer-related concepts have not yet been precisely defined. In order simply to classify the data on problems in use, the group needed to develop a thesaurus of terms, with definitions and cross-referencing, indicating the related terms, broader terms, and narrower terms for each item. The group is using a database program structured according to the thesaurus for storing the problem examples of the study. This makes it possible to find an example of a specific problem under the several related terms that might describe it.

The group's current plans include a followup survey for more detailed information on applications use, classroom observations to focus on problems in student use of software, and further consideration of whether it would be useful for the group to develop and test its own model curriculum using applications software.

Speech Recognition

The development of a reliable, low-cost speech recognition device appears to hold considerable potential for education, especially for tasks in which speech is essential, such as early reading instruction. Although there are many contending theories about the cognitive psychology of the reading-aloud process, and perhaps an equal number about the most effective way of teaching word recognition, the act of reading words aloud seems essential to learning to read. In the past the learning process has demanded the presence of a skilled reader to confirm the beginning reader's efforts. Speech recognizers may enable a

microcomputer to discern whether a child has read a word correctly. Used with imagination and care, this capability could facilitate powerful computer-based supplements to traditional reading instruction.

In June 1984 a field test was carried out which focused primarily on the human factors issues associated with the use of a recently-developed speech recognizer in early reading instruction. The device used is the Mark II Isolated Word Speech Recognizer recently developed by Dragon Systems, a research and development firm in Newton, Massachusetts. Dragon's recognizer can be sold for well below $500 and performs at a 99.3 percent accuracy level on a standard test of isolated word recognition. Earlier recognizers have been either prohibitively expensive or too poor in performance to support widespread educational use. High quality recognizers have typically been priced in the tens of thousands of dollars. The best-known low-end recognizer (priced $500-1000) performs with only 88 percent accuracy. Speech recognition experts have established that performance below 97 percent is too frustrating for practical use. The application used in this field test also included high quality speech output capability, based on digital coding of actual recorded speech.

The Mark II is designed as a speaker-dependent system. Although speaker independence is considered preferable in many applications, as it does not require speech samples from each new user, a speaker-dependent system seems more suited for use with young children because of the variability in their speech. Each user must initially "train" the system by giving it a few samples of his or her pronunciation of the words to be recognized. For each word, the system constructs a template against which it compares the user's subsequent utterances. Although the Mark II is limited to small vocabularies at a time (16-32 words), its development signals the advent of the high-performance, low-cost recognizer.

Seventeen kindergarteners, aged five to seven years, in a public elementary school in Watertown, Massachusetts, participated in the study. Equal numbers of poor, average, and good readers were selected by their teachers to take part in the experiment. The test included three parts, and centered on the learning of eight words. Pretesting showed that 14 of the children could read none of these words; the others could read one to four of them.

First, the student "trained" the system to recognize his or her voice by giving four samples of each of the words to be recognized. Next, a story containing these words was presented to the student through speech output, screen graphics, and music. The student moved the story along by correctly pronouncing the focal words when they appeared on the screen. Finally, the student played a game, in which the eight words were presented on the screen in a 3x3 matrix with one blank cell. The object of the game is to move the word in the lower left corner to the upper right corner, by moving words in and out of the empty cell. Words are moved by pronouncing them. The graphics, music and reading software for this lesson are prototype versions of software under development (without NIF support) by Educational Development Center.

The entire procedure took 15 to 20 minutes and was conducted in a separate room in the school. Noise levels were recorded with a sound meter, and each session was videotaped. Observational data were collected on machine errors and on a range of human factors issues, such as children's responses to machine errors, children's comprehension and imitation of speech output, children's use of the microphone, and their allocation of attention between the speech system and the learning activity for which it is used. Students were also interviewed to determine their overall reactions to the experience, what they liked most and least, and how they would like to see the system changed.

While the data are still being analyzed, results are available concerning causes of machine error, students' comprehension of speech output, overall interest, and reading progress. A microphone stand allowed the training to proceed smoothly, while a hand-held microphone tended to increase the frequency of machine errors. The method used to produce speech output worked extremely well; students had no trouble understanding the speech output. They also found the training interesting and enjoyable; even when the recognizer malfunctioned, they maintained a high level of interest and were eager to continue. By the end, eight of the seventeen students were able to read all eight words. The remaining students could read from four to seven words. Two additional rounds of testing are planned.

State-of-the-Art Software and Educational Television

Educational television and microcomputers are technologies with different features that may have complementary educational potential. Television has been shown to be a powerful medium for representing knowledge and influencing learning and cognitive processes. As traditionally used, however, it lacks opportunities for viewers to interact with the material. The microcomputer promotes such interaction, but lacks the ability to provide real-life moving visual images. In spite of the growing availability of both educational television and microcomputers in the schools, little has yet been done to coordinate and integrate the two technologies, and to explore how their combined use can create new possibilities for teaching and learning that go beyond the individual technologies.

This project is one of three which the New Technologies group has developed to investigate different combinations of television and computer materials for educational uses. In this project the group is investigating recently-developed educational packages combining television, software, and printed materials, which require no additional technology beyond the ordinary microcomputer and television set and no direct electronic connection between the video and computer components.

During the summer of 1984 group members surveyed the field for existing examples of materials which combine television, software, and print, and selected for the study two of the most recently developed and widely publicized packages: Bank Street College's The Voyage of the Mimi, and the Agency for Instructional Television's Solutions Unlimited. The first package presents a variety of scientific/mathematical concepts

in real-world settings, and is designed to lead children to see science as an exciting and rewarding human enterprise. The second aims to improve problem-solving skills. The Mimi materials have just become commercially available (the package costs $1200, although some project components are not yet complete), and the Solutions materials will be available in January 1985 (cost $95).

The Voyage of the Mimi was developed for use in grades 4 through 6 and is applicable through grade 8. Thirteen 15-minute television episodes (broadcast weekly and available on videotape) follow the dramatic adventure of the Mimi, a sailboat that has been chartered for the summer to search for whales. In addition to the dramatic episodes, each program contains a 15-minute "expedition" where cast members appear as themselves and expand on a wide variety of scientific and mathematical concepts that the dramatic adventure has raised. The software is divided into four learning modules containing games and simulations that are intended to help expand the concepts introduced in the television portion. The printed materials include both student and teacher guides with additional learning activities and teaching strategies.

Solutions Unlimited was developed for grades 6 through 8, and includes eight different problem-solving units presenting general problem-solving strategies. For example, the unit "Who Says So" is about judging sources of information when problem solving. Students have to decide which sources of information are most reliable as they attempt to evaluate the accuracy of conflicting newspaper reports. In each unit, the video portion presents vignettes of a problem, or demonstrates a problem-solving skill. The software presents exercises for students to work at individually or in small groups. The printed materials are used in conjunction with each unit and provide additional exercises and suggestions for using the unit in the classroom.

This fall the group is locating classrooms which plan to use one of these packages, and has begun to develop a research plan to explore three areas:

(1) the process of designing effective multimedia packages involving software, television, and print materials;

(2) how an integrated package such as Mimi or Solutions can be successfully incorporated into the classroom; and

(3) the effects of these multimedia packages on learning.

Thus the two existing packages are being studied as a means to gain information about design and curriculum integration of future packages.

The research plan includes observations of classroom use, analysis of design features both as formulated by the authors and as they appear to emerge in use, interviews with teachers and students about their perceptions of the materials, and assessments of student learning of both subject matter and attitudes toward science.

Interactive Video

This project is studying the design and uses of interactive videodiscs created from existing television material. The group plans to develop a videodisc that will deal with one or more scientific concepts or topics and that will employ several different interactive formats. The group will then use the videodisc with students to explore three questions:

(1) Design. What criteria should be used in selecting video material suitable for retrofitting and what concepts in child development and science education should be taken into account in designing videodiscs?

(2) Effectiveness. What are the effects of different presentational and interactive formats on the appeal of the videodisc for learners and on learner comprehension of the material presented?

(3) Environments. What is the nature of the child/machine interaction, the potential for group participation, and the role of the teacher in making educational use of an interactive videodisc?

During the summer and early fall, the group reviewed existing television programs from 3-2-1 Contact and Nova, two television shows that deal with science material. Programs from both shows were reviewed with an eye toward selecting segments that could be incorporated into a videodisc that will address a science topic for an audience of upper elementary and junior high grades.

Staff members at WGBH (which produces Nova) and several science educators reviewed over 100 Nova shows to select material that was both appropriate to the junior-high curriculum and that dealt with one of the "targets of difficulty" in science identified by ETC working groups. In selecting portions of programs that fit these criteria, reviewers identified programs that dealt with one of the following themes: the complexity of ecosystems, conflicts between human uses of resources and balanced ecosystems, or competition between humans and other animals. All three themes deal with material related to ETC research projects on Complex Systems and Scientific Theory and Method. Staff members at Children's Television Workshop reviewed 3-2-1 Contact programs. They identified forty-two segments that deal with one or more of the four targets of difficulty being studied by ETC research groups on science.

In reviewing these selected television program segments, the project team refined its criteria for choosing material for the videodisc. The team decided to focus on one theme, "Hypothesis Testing," related to the ETC research group Scientific Theory and Method. Criteria for selection of video material include three main considerations: the visual appeal of the material, the relevance of its content to hypothesis testing, and the extent to which the material can be effectively presented and enhanced using interactive videodisc technology.

During the coming months the group will refine its design and product the videodisc, with major contributions from Interactive

Training Systems. Plans for evaluating effectiveness are being developed. The group expects th. disc and related software to be ready for field testing with students and teachers by late spring 1985.

Science Network

After many conversations with science teachers about the problem of isolation from both colleagues and ideas, a group at ETC began to consider how, if at all, technology might address this frequently stated concern. For many businesses, computer networks have served an import-nt role by linking organizations and individuals; the group was curious about how this model might apply to education. settings.

In February 1984, research began on the ways that computer networks were being used for educational purposes. A handful of universities had recognized the potential of this technology and had developed a number of trial inservice programs for interested teachers who had access to computers. Although all of these networks began by addressing the needs of the teacher, most of the projects had shifted the focus to the student because of a minimal teacher response. This shift is unsettling for two reasons. First, the informal response by teachers in discussions about the concept of networking is usually quite positive. Second, unless an educational network can address the needs and interests of both teacher and student, it will not become an integral part of the classroom curriculum.

The ETC group became curious about the reasons behind the lack of teacher response and hypothesized that the network had not been adequately introduced to teachers and did not respond to their needs. It decided, therefore, to develop the idea of a content-based network revolving around ideas and activities of interest to teachers and of use in classrooms: an electronic community of peers. Toward that end the research group met with a group of science department heads from Boston area schools. The response of these teachers to the proposed project was overwhelmingly positive.

The next step was to explore what type of equipment would be the most app.opriate for such a network. After looking at mainframe computers, minicomputers, and microcomputers, the group decided to develop a network on a r .ocomputer with a hard disc. There were several reasons for this decision. First, the group felt that the size of the network would be an important factor in creating its community. In this case, bigger did not necessarily mean better. The object was not to have participants from all over the nation, but rather a regional or even state-wide network of 20 to 30 individuals. The group was interested in exploring a model that might be duplicated by school systems, state departments of education, resource organizations, or universities. In this regard, it wanted to create a system that could be replicated without a large expenditure on the part of the central institution. And, the group found that people were better able to conceptualize the network if told it would take place on a microcomputer rather than on a larger machine. Conceptual understanding may be a key to the success of network.

ETC has begun the implementation of such a network by addressing the problems of software and documentation, participant selection, topic development, and research objectives and evaluation. After reviewing the existing network and electronic mail software, the research group decided that no existing system was at once simple enough for the naive user and appropriately powerful for the project's needs. As a consequence ETC will develop a network software package which will include both personal and large group conversations, as well as data storage. When finished, the ETC network software will be placed in the public domain and would then be available for use by others interested in implementing the model.

ETC will invite the New England members of the National Science Teachers Association to apply for participation in the network and will select participants from this group. The content of the network will include discussions led by scientists involved in research of interest to teachers; by individuals who can serve as regional resources to teachers, such as educational staff from a science museum or aquarium; and by teachers who have developed unique approaches to difficult curriculum topics.

The research focus of this project is to explore what elements of a network make it successful and what types of conversations among participants are most significant to teachers. The network should be operational in pilot form by mid-winter of 1985, and preliminary network conversations should get underway in early spring.

National and Local Networks

As groups shared information about the various research projects being considered or currently underway, cross fertilization occurred and in some cases new projects were added to existing groups. Such is the case for the third project of the New Technologies working group, which involves the use of computer networks and television. Researchers in the New Technologies group realized that computer networks combined with educational television could provide educators with a variety of opportunities, such as obtaining up-to-date, broadcast-related, curriculum materials through computer channels or establishing a network of classrooms working on science projects based on television programs.

Building on the program resources of WGBH and CTW, two of the collaborating organizations in the ETC consortium, we play to explore two uses of computer networks in connection with the science programs <u>3-2-1 Contact</u> and <u>Nova</u>. The first of these will involve the distribution of the <u>Nova</u> Teacher Guide and the <u>3-2-1- Contact</u> Teacher Guide and Resource Manual on one of the large public access computer networks, Compuserve. The second network will involve a local pilot study of six classrooms which will communicate through the computer network with one another as they conduct research projects based on one or two of the <u>Nova</u> shows.

The development of each of these projects began this fall. We currently are exploring a major dissemination of broadcast-related

materials through an existing national network. Activity on the local network will begin in the winter of 1984-85 with the selection of six pilot sites for a two-year project. Year I will combine classroom experiments based on the Nova programs with computer analysis. A meeting with teachers will be held in the winter to select two Nova programs to be used for the experiments and to decide on appropriate research questions and procedures. Classroom experiments and computer analysis of the data will be conducted in the spring and analysis of this information will be completed in the summer.

During Year II of the project the use of computer networks will be added to the above design to allow classrooms an opportunity to develop a collective data base for analysis by individual classrooms and a vehicle for scientific discussions among classrooms. At this time the ETC network will have been in operation for at least six months and should be able to incorporate this project into its functioning.

AGENDA BUILDING

The Center represents an extremely diverse set of constituencies, and its work embodies a wide range of issues. The two interact throughout its structure, especially in the research groups, but they receive formal attention in the Agenda Group. The Agenda Group comprises senior representatives from each of the organizations in the Center collaborative. It has two specific tasks in addition to serving as the Center's steering committee: to oversee the Center's own research program, and to consider the Center's research program in light of research questions and projects elsewhere in the field.

During this first year the Agenda Group has concentrated on the first of its two tasks, overseeing the Center's research. The highly focused "Targets of Difficulty" model guiding most of the Center's research carries with it a substantial risk, namely that it will yield projects too narrowly clustered within the broad domain of interest. The Center's emphasis on research groups working collaboratively to identify and pursue research questions is also risky, in that it requires specific mechanisms to make sure all projects meet reasonable substantive and methodological standards. The Agenda Group devoted a major share of its time to reviewing individual research projects within the Center, with particular attention to individual projects' satisfaction of reasonable methodological norms and to the distribution of the set of projects across the Center's research domains. As the Agenda Group did its work, it began to devote attention to a third area, the identification of findings or themes which emerge across diverse research projects.

There was, for example, a long discussion in early spring of the degree to which different projects' plans implied a set of design criteria for educational software. There did in fact appear to be some consistency among different groups' views of how software and child should interact. (Neither evaluation of students nor fancy graphics figured in this apparent consensus; firm subject-matter focus and clear feedback did.) The question was whether this reflected a collective sense of what had been learned from the field's experience with educational software, or a set of essentially unsubstantiated (though probably valid) beliefs shared by the members of the research groups. The Agenda Group's discussion made two things clear: there was some evidence, albeit informal, that the apparent software model was based on the field's experience; but this evidence fell far short of proving the point. Therefore, the Center's research projects should attend carefully to the danger that beliefs about software might become findings without empirical interference.

Another example of a cross-cutting theme concerned sex differences in children's reaction to computers in schools and at home. That such differences are widespread is widely acknowledged. At the same time the basis for the differences and their consequences are widely debated. The Center is frequently asked why it does not have a research project focused on this issue, or on the parallel issues of racial, economic, geographic, and social-class differences. The answer, which emerged from several Agenda Group conversations, is that the topic does not submit

readily to broad inquiry. Rather, it is a topic which requires attention whenever research examines interactions between technology and children. This requirement entails some guidelines for Center research, namely that it involve interactions with both boys and girls and that it pay attention to differences arising from sex differences or other differences among children. This is an instance where general attention by the Agenda Group to the field's research agenda had a specific impact on the Center's several research projects.

The Agenda Group is led by Charles Thompson of Education Development Center, and its staff work is done at EDC rather than at ETC headquarters. This division both maximizes the independence of the group from the formal ETC administrative hierarchy, which has a natural tendency to defend current practice, and permits the Center's co-Directors and other senior administrators to be collaborators in rather than leaders of its discussions. The Agenda Group meets approximately monthly, with a denser schedule in early fall and late spring.

In future the Agenda Group will divide its time more evenly between attention to the Center's own research, and attention to the broader research agenda in the field. Instead of producing only one major report on the Center's research agenda, as it did during the first year, it will produce a major topical report each winter (which may or may not speak directly to Center activities), and a research plan for the following year each spring.

TRAINING, CONFERENCES, AND DISSEMINATION

The Center sponsored two major conferences during its first year. We also ran two two-day Institutes on Computing in Schools, presented a series of seminars open to the public, published the first issue of a newsletter, and sent senior staff members to meet with a large number of relevant professional and scholarly groups.

Conferences

The Center's first conference took place in February, with a focus on the Targets of Difficulty model which by then had become a strong influence on its research. The object of the conference was to share the model with a large number of participants from different Center constituencies (but not necessarily involved with the Center), and to solicit the views of a few distinguished scholars on the targets of difficulty that existed in their fields independent of what material from those fields was taught in schools. There was a less substantive purpose to the conference as well: as our first major public event, it served to symbolize the Center's existence.

The first presentation at the Founding Conference was from Manuel Justiz, Director of the National Institute of Education, who spoke about the Center's expected role within the federal government's programs to advance educational technology. The other presenters were

Judah Schwartz: Targets of Difficulty: An Introduction to the Metaphor

Andrew Gleason, Charles Whitney, and William Bossert: Targets of Difficulty: Views from Disciplines

Robert Kilburn, Deborah Ross, and Katherine Merseth: Targets of Difficulty: Views from Practice

Gregory Jackson: Concluding Remarks

There were roughly 100 participants, mostly teachers and some faculty from surrounding colleges and universities or staff from the area's hardware and software industries. Sessions began Thursday evening and ran through Friday.

The Center's second conference was in July. Its object was to present and examine instances where technology had been used effectively in schools to teach specific subjects. In organizing the conference, therefore, we recruited teachers who had done interesting work in their classrooms to make major presentations, and recruited university faculty and technology professionals to be respondents. There were sessions concentrating on mathematics, on science, on language, and on the computer as an object of study. The conference, entitled "The Computer as Teaching Tool: Promising Practices", drew about 100 participants and was extremely lively. Most striking were the sophistication of the applications presented and the rapid movement of discussion to

fundamental questions of pedagogy and subject matter rather than **technical detail.**

Presenters at the Promising Practices conference, which like the Founding Conference ran from a Thursday evening through the ensuing Friday, included

William Read: What Can Second Graders Learn About Space Flight from Dynaturtles?

John Samp: Using a Thermistor and Microcomputer to Study Concepts of Heat and Temperature with High School Students

Jon Choate: Using Visicalc and Dynamo to Make Models and Solve Problems in High School Math Classes

Richard Houde: The Geometric Supposer: A New Approach to Problem Solving in Mathematics

Alan November: Tool-based Software as the Focus of a Computer Literacy Course: Problem Solving, Teamwork, and Self-Esteem

Paul Goldenberg: Programming with Ulterior Motives

Fay Wheeler: Using a Database Program in a Thinking and Writing Skills Curriculum

Cindy Stevens: Using Quill, a Computer-based Writing Program, with Elementary School Classes

Respondents to the various sessions were Hal Abelson and Judah Schwartz (science), Patricia Davidson and Susan Friel (mathematics), Beth Lowd and Jane Manzelli (computers), and Henry Olds (language).

The Center plans to sponsor three conferences during the coming year. The first, in November, will be supported by the Ford Foundation rather than NIE due to its focus. It will bring together a small group to think about issues surrounding computers in urban schools. The topics of the later conferences are not yet set, though they are likely to include software design, staff development, and some presentation of our own work in progress.

The Institute on Computing in Schools

To meet its contractual obligations to provide graduate-level training, ordinarily not part of an NIE R&D center's mission, the Educational Technology Center co-sponsors these Institutes with state Departments of Education in New England. Each Institute begins with dinner and an evening presentation (thus far always on Friday) and continues with three more presentations the following day. Two of the presentations concentrate on computer applications within particular subject-matter areas, and the other two concentrate on organizational

and human-resource issues which arise around educational technology. Typically one of the context presentations is on staff-development issues, and is by one or two individuals known for their contribution to technology-related staff development in the state.

The Institutes are designed to be largely self-supporting, except for the cost of bringing Institute trainers and support staff from Cambridge to the site and, in some cases, the cost of special equipment such as video projectors. Participants pay just under $50 to attend the Institutes, the idea being that the fee should be well within the unsubsidized reach of interested teachers.

The first Institute, in the marble-quarrying town of Proctor, Vermont, was in January. The site was Proctor High School, a striking structure faced in stone; the major concurrent activity was a high-school dance Friday evening. The presenters were Judah Schwartz of the Center, on applications in mathematics; Colette Daiute of Harvard, on applications in writing; Frank Watson of the University of Vermont and John Burton of Champlain College, on staff-development issues; and Greg Jackson of the Center on decision-making issues. The approximately 40 participants proved a lively audience, with much discussion of how ideas about technology disseminate and of teacher's role.

The second Institute was held in April in the centrally located town of Hamden, Connecticut. The program was similarly structured. Carol Chomsky spoke about applications in language, replacing Colette Daiute's presentation. Judah Schwartz spoke on applications in science rather than mathematics. The staff-development presentation was by Richard Nolan of the Bristol, Connecticut, public schools. Sessions were held at a regional educational center rather than a school. As we noted in the introduction to this document, although the structure of the Connecticut Institute was similar, its audience was quite different from the Vermont one, but even so, the level of discourse and the degree of participant satisfaction were high.

We had intended to run three Institutes in the first year, but our contacts in Maine, the site of the third Institute planned for late spring, asked that we defer it to fall. (It subsequently was postponed further, because of unexpected schedule conflicts.) Other Institutes during the second year will be in New Hampshire, Rhode Island, and western Massachusetts. The New England focus arises, of course, from the NIE contract restriction that the Center's NIE-funded school-based activities serve New England in its initial three years. However, the Institute model will extend readily to more distant sites; one of our objectives is for the Institutes gradually to spread and to become self-supporting and self-perpetuating.

Seminars

The ETC Seminar Series is a mechanism for exposing the Center community, broadly defined, to the views of a range of individuals whose work or thoughts bear (or should bear) on educational technology. The cost to the Center is essentially that of printing and distributing

posters, plus an occasional reception, and we thus have felt free to define the domain of the Seminars very broadly. Seminars generally are Tuesday afternoons, approximately every three weeks.

The Seminars during the Center's first year and a half were as follows:

Judah Schwartz: Intuition and Microcomputer Software in High School Physics

Carol Chomsky: Thinking About Language Software

Deborah Ross: Computers for Kids -- A Model of Educational Reform

Susan Zelman: Individual Differences and the Computer Learning Environment: Motivational Restraints to Learning Logo

Richard Houde: The Geometric Supposer: A New Approach to Problem-Posing in Mathematics

Sue Carey: Acquisition of Scientific Knowledge: Conceptual Changes in Childhood

Marc Tucker: The Economic Context for Educational Technology

Herbert Ginsburg: Children's Mathematical Thinking: Workshops for Educators

Andrea DiSessa: Design Considerations for Computer Systems in Education

Colette Daiute: Using Computers to Develop Writing in the Elementary Grades

Sherry Turkle: The Second Self: Computers and the Human Spirit

Bram Arnold, Paul Lyons, and David Olney: Computer Applications for the High School Content Areas: Math and Science

Janet Baker: Talking to Your Computer: Prospects for Speech Recognition in Education

Sheldon White: How Children File Useful Information

We expect attendance this year to be similar to last year's: a minimum of about 20 and a maximum of about 100 teachers, faculty, graduate students, technology professionals, and others. We experimented during the first year with rotating sites, and this persuaded us to have a single site for seminars this year. We may, however, experiment with cable-based mechanisms for involving audiences at different sites in a given Seminar.

Newsletters and Other Documents

The Center published an external newsletter, ETC Targets, in August. It summarized the research in progress at the Center, and in addition discussed the principles underlying that research. Targets went primarily to math and science coordinators in school systems across the nation, with additional mailings to key professional associations and individuals who had asked to be on the Center's mailing list. A major problem in disseminating the newsletter widely was the Government's rule that we print no more than 5,000 copies; we will seek a waiver in future to make the newsletter more effective.

We expect to publish two further issues of Targets this year. The first of these will discuss the Center's new-technologies research, whose details were still under discussion when the first issue went to press. The second will discuss the findings emerging from the Center's research projects as they move through the pilot phase of their work.

ETC Targets is not the only publication describing the Center's work. The Research Agenda, which was delivered to NIE in March, circulated in draft form for comments, and as interested individuals became aware of, it they requested copies. Several hundred copies of this document are now in circulation, in addition to numerous copies of copies, and it has contributed mightily to the field's awareness of ETC activities. The Center also publishes an internal newsletter, ETCetera, to keep its rather large group of insiders informed, and inevitably copies of this publication make their way outside the Center.

During the second year most Center research projects will produce at least two technical reports, in addition to the documents which emerge from the Agenda Group and the Center newsletters. These will be available in hard-copy form by request. We will also experiment with an electronic service whereby interested individuals can connect a terminal or microcomputer to a facility which will permit them to browse through the full text of existing documents (probably subject to time limits), order copies, and perhaps record comments or queries.

THE FUTURE

As we look into the future of the Educational Technology Center three points stand out: that the Center will grow, that as it grows it will continue work on several important unresolved issues, and that it will begin to produce results. In this conclusion we will comment briefly on each point.

Growth

The Center's funding from the National Institute of Education was just over $700,000 in its first year, and it is just over $1.1 million in the second year. The Center's contract with NIE calls for significant growth in the third year as well, followed by relative stability.

But NIE is not the only source of ETC funds. Currently, for example, the Center receives funding from the Ford Foundation (for a conference on computers in urban schools) and from a group of high-technology firms organized as the Industry Group of the Educational Technology Center. The clear implication of this is that growth will be a major attribute of ETC over the next few years.

The Center's NIE contract calls for it to focus on the role educational technology can play in improving math, science, and computer education in kindergarten through twelfth grade. The Center's interests are somewhat broader, and we hope to do work in several of the following areas:

(1) Postsecondary education. Many of the same questions which have arisen in the Center's current work arise also in colleges, universities, and other postsecondary institutions. We believe parallel research on postsecondary educational technology would be appropriate and desirable as ETC grows.

(2) Nontraditional education. Educational technology is far more widely used in industrial and corporate training programs than it is in schools, colleges, or universities. Yet the basis for and effects of its use have received little attention. Research on educational technology in nontraditional settings is appropriate not only for its own sake but for what it can tell us about possible future applications in traditional settings.

(3) Home education. Television commercials imply strongly that a computer in the home can lead to success in school. This is the basis for many computer sales to homes, and for much concern about the disequalizing effects of home computers -- which are found disproportionately in affluent homes -- might have. However, little is known about whether and under what circumstances children learn from computers at home, and this is an area that ETC would like to investigate.

(4) Other disciplines. There are good reasons to do research on educational technology in math, science, and computer education.

There are also good reasons for parallel research involving other disciplines, such as language (read, written, or foreign), humanities, and the various social sciences. ETC intends to expand its research into these other disciplines.

Funding for these new areas of research likely will come from sources other than the National Institute of Education. Scheduled increases in the Center's NIE funding will go largely toward meeting the expenses of existing projects as they enter more expensive phases; toward beginning work on new projects within the math, science, computer-education, and new-technologies domains; and toward expanded dissemination of results.

One mechanism for bringing new research to the Center is already in place. Beginning this fall ETC established an Industry Group, and invited several high-technology firms to participate. Each firm sends a senior representative to quarterly meetings of the group, at which the major topic is expansion of the Center's research. Each firm also contributes a modest annual sum to a special research fund, which is then used to begin work on deserving projects. As of November 1984 the ETC Industry Group has four members, and we expect to add a few more before its first meeting in January.

Another aspect of the Center's growth concerns the expansion of its collaborative. Originally this was to have involved adding school systems to the collaborative from elsewhere in New England. However, during the first year, it became clear that this original plan would involve more counterproductive logistical headaches than it would substantive expansion of the collaborative. What the Agenda Group has decided to do, instead, is to solicit applications for satellites to ETC, each comprising a research organization and several schools. Each of these satellite sites would then undertake one or two research projects following roughly the current Center model, and would be represented on the Agenda Group. ETC would provide some funding to such satellites during their first two years, and encourage them to find local or state support beyond then. There will be one such satellite during this year, and if that proves successful, several more in the following year.

Unresolved Issues

The Educational Technology Center operates in largely uncharted waters, both organizational and substantive. Three issues have been persistently difficult, and as we expect them to continue with us, we will comment briefly on each.

(1) Specialization and equal participation in collaborative research. The Center's research groups comprise very different sorts of individuals: teachers, curriculum specialists, scientists, graduate students, educational technologists, educational researchers. During the first year much of these groups' work involved presentation, discussion, and argument centered on targets of difficulty. In the second year much of their work involves pilot

research, and here some members have -- or believe they have -- specialized skills that others lack. There is a natural tendency, in these circumstances, for groups to divide into "doers" and "reviewers", but this natural tendency runs against full collaboration. Striking the right balance has been, and will continue to be, extremely difficult and delicate.

(2) Subject matter and technology. From its beginning as a government Request for Proposals, the Technology Center has been torn between a commitment to improve instruction within disciplines, which implies one way of choosing research projects, and a commitment to find educational uses for new and exciting technologies, which implies another. The two are often compatible, and thus in practice we do not see this as a major problem. However, many outsiders perceive the Center to be insufficiently technological for its mission, and since others' perceptions stem in part from our activities this is of concern to us. Here, again, the problem is to find and maintain a delicate balance.

(3) Learning environments and schools. Much of the advocacy for educational technology stems from its ability to individualize instruction, perhaps to the point where collections of learners -- schools -- become less important. Yet much of the Center's charge has to do with improving instruction in schools. In an ideal world a center such as this would focus simultaneously on the psychology of individual learning and the improvement of school practice. But this is not an ideal world, partly because the available resources and time are finite and partly because the two foci imply different and largely incompatible research approaches. We have tried to see that the choice of Center research projects reflects our concern for improving school practice, and that these projects methods reflect our belief that one cannot improve educational practice without careful attention to the psychology of learning. The tension remains, however, and we expect that it will remain in the future.

Products

It is tempting, when working within a web of contract clauses, federal procurement regulations, and University-sponsored research rules to think of research products in molecular, concrete, and relatively narrow terms. From this perspective the products of the Center's work are its reports. These will be numerous and varied: topical and planning reports from the Agenda Group, progress and technical reports from individual research projects, newsletters and summary reports comprising the traditional portion of the Center's dissemination activities, and general reports such as this on the Center's overall progress.

But this is not the way we think of the Center's products. Instead, we see the Center producing incrementally more accurate and useful answers to broad questions about educational technology. Much of the Center's research and many of its other activities are motivated by two such questions:

(1) When does it make sense to use technology in education, particularly in schools?

(2) When it makes sense to use technology in education, under what conditions is it reasonable to expect such use to be productive and efficient?

Our overall research strategy, which combines a focus on "targets of difficulty" with careful attention to new technologies, seeks answers to these questions both in very specific settings and, through aggregation and synthesis, in the general case. We thus see the Center producing four kinds of products as its work proceeds:

(1) Specific models for the use of educational technology to teach -- or, more likely, to help teach -- specific subject matter within mathematics, science, or computer education (or other fields, as the Center's research expands). If, for example, the heat/temperature project finds that the combination of its heat and temperature probes, the corresponding software, and the curricular units it develops help children understand the distinction between heat and temperature better, then these findings will be a product of the first type.

(2) General observations about the non-technological elements which seem crucial to the success of educational technology: teacher experience and skill, classroom structure, time on task, supporting materials, and so on. Most educators serious about educational technology are coming to realize that the major obstacles to the effective use of educational technology stem from the cost and difficulty of modifying its surround appropriately, rather than from the cost of hardware and software. Yet it is not clear which features of the surround are critical, nor what the most productive configuration might be. We expect to advance understanding in this area by observing commonalities among the Center research projects as they move out of the pilot phase.

(3) Simple design principles for educational technology, and particularly for software. There have been several generations of assumptions about how good educational software should look. The earliest emphasized rewards for right answers. Later generations have emphasized play value, particularly resemblance to videogames, and the presentation of material in intrinsically absorbing forms such as mystery solving. We hope that as our research proceeds we will get a sense of which software attributes seem generally desirable or undesirable, and which vary in importance.

(4) General models for the use of educational technology. We do not believe there is _a_ general model for the use of educational technology, any more than there is one correct pedagogy for all teachers or curriculum for each subject. But we also believe that there will be certain combinations of hardware, software, teacher preparation, classroom structure, curriculum, and supporting materials that are particularly likely to be effective in different subject-matter and grade-level contexts. Pointing the way towards

these, and perhaps even finding them, is a major product we hope to deliver.

The Educational Technology Center's reports over the next few years will speak to a wide range of specific applications and general themes. We fully expect that their aggregation, combined with the Center's other activities, will come to constitute products of the sort we outlined above.